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Research Article

Case Study on Analyses of Slope Riverbank Failure

Nazaruddin Abdul Taha,[1] **Mohamad Shakri Mohmad Shariff**,[2] **and Mohd Azizul Ladin**[1]

[1]*Faculty of Engineering, University Malaysia Sabah, 88400 Kota Kinabalu Sabah, Malaysia*
[2]*Faculty of Engineering & Quantity Surveying, INTI International University, 71800 Nilai Negeri Sembilan, Malaysia*

Correspondence should be addressed to Nazaruddin Abdul Taha; nazardin@ums.edu.my

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A slope riverbank failure is a natural event that occurs globally on each riverbank, and a drawdown event usually causes slope riverbank failure. This case study is aimed at analysing slope riverbank failures by evaluating the seepage and slope stability of the riverbank under slow and rapid drawdown. The riverbank in this case study is located at KM 3.49, Jalan Pantai Luagan in the Sipitang district (N 4° 59′ 12.9″ E 115° 31′ 13.3″). A literature review was conducted to view the current study pattern and retrieve a methodology based on the current study pattern. GeoStudio is a commercial finite element software. The data obtained from the borehole log report and online resources were utilised to create the riverbank model in software. The phreatic line shows a slow change over time, indicating that the riverbank takes a long time to stabilise after the drawdown. The FOS value decreases during the drawdown occurrence and slowly increases after the drawdown has ended. In conclusion, the drawdown event can cause slope riverbank failure, and the seepage and stability analysis using GeoStudio can show the condition of the riverbank during the drawdown event.

1. Introduction

Slope instability or slope riverbank failure can be considered one of the reasons for stagnant economic growth [1]. It often results in economic loss for the community. Along with financial loss, occasionally, there is a loss of life. Numerous reasons contribute to the failure of a riverbank slope, and these variables are frequently interconnected. Hence, it is crucial to analyse slope riverbank failure. The analysis of slope riverbank failure will provide a clear view of the failure pattern at the site location and provide the info needed to propose a solution for slope riverbank failure. An approach can be proposed to treat the slope failure from the analysis. Slope stability analysis can be performed to analyse slope riverbank failure. Slope failure happens due to slope instability; an analysis of slope stability using suitable parameters will better understand the failure pattern based on the factor of safety obtained. Through the analysis of slope riverbank failure, valuable data regarding the slope riverbank's onsite location can be retrieved, such as a suitable slope gradient for the riverbank. The data retrieved can be used as a reference to design a proper slope embankment or upgrade the initial slope using a relevant approach. More importantly, the analysis will help prevent future occurrences of slope riverbank failure.

The analysis will reveal unfavourable low safety factors, and strengthening steps should be implemented. When a slope fails, and remedial work is required, it is critical to conduct a slope failure analysis to ascertain the likely causes of the failure. Appropriate remedial design can only be implemented when there are identified failure causes.

Slope riverbank failure is a natural event occurring globally on riverbanks worldwide. Slope riverbank failure is a common result due to slope instability. Various factors cause slope instability, such as rainfall, a rise in the groundwater table, seepage, rapid drawdown, or a shift in stress conditions. [2] also mentions that the rapid drawdown often causes slope riverbank failure during and after flood events

or high flow periods. Furthermore, slope instability problems on both built and natural slopes are common concerns for researchers and professionals [3]. According to [4], slope instability is one of the significant problems in geotechnical engineering where the loss of life and property can occur. The steep riverbank failure is a significant concern in the economy, society, and the environment since it affects all three aspects. It requires a proper strategy to manage the issue properly. One of the proper strategies is to analyse slope riverbank failure.

In this paper, the approach chosen to analyse slope riverbank failure is by determining the slope riverbank stability under drawdown conditions by using a GeoStudio. The reasons for choosing the GeoStudio include its ability to combine analyses that use different products into a single modelling project, using the results from one as the starting point for another. These approaches show a clear view of the slope riverbank conditions under drawdown conditions. This study is aimed at analysing slope riverbank failures by conducting seepage and stability analyses using GeoStudio. The following are the study's objectives in brief:

(i) To conduct the seepage and slope stability analysis in slow and rapid drawdown conditions

(ii) To evaluate the change in pore-water pressure under rapid and slow drawdown

(iii) To determine the change in factor of safety over time under rapid and slow drawdown conditions

2. Case Study

The case study will be based on a riverbank located at KM 3.49, Jalan Pantai Luagan in the Sipitang district (N 4° 59′ 12.9″ E 115° 31′ 13.3″). Figure 1 shows the site location of the riverbank along Sungai Mengalong, retrieved by Google Earth Pro. The research will then refer to two borehole log reports from Konsultan Azam Sempurna. BH1 was buried on the road, and BH2 was sunk in the centre of the slope, as shown in Figure 1. The borehole log report will be used to analyse slope height, slope angle, water level, soil type, and shear strength.

3. Current Pattern of Study

Gottardi et al. [5] have conducted a study of river embankment stability under transient seepage conditions. In the study, the initial condition and the hydraulic parameters were assigned. The seepage analysis was carried out using VADOSE/W, a finite element software. The study's results showed that the definition of initial conditions is a key part of analysing transient seepage and that the relevant assumptions greatly impact how stable the riverbank is over its lifetime

Then, [6] analysed rapid drawdown scenarios for levee design. The researcher used seepage and slope stability analysis using VSLOPE®/SVFLUX™ software to evaluate the effect of rapid drawdown on the riverbank. The hydraulic properties are assumed for each region in the numerical

Figure 1: The site location of case study.

model. The findings from the study concluded that the factor of safety rapidly falls below 1.0 with the original selected hydraulic conductivities (after approximately 2 hours) due to the high pore-water pressures retained in the earth structure after the lowering of the reservoir level. Then, the impact of rapid drawdown may vary with the multiple layers in an earth dam based on the hydraulic conductivity of the individual layers. In addition, the safety factor decreases during rapid drawdown and then gradually increases as the pore-water pressure decreases.

Himanshu and Burman [7] had performed a seepage and slope stability analysis of the earthen dam. SEEP/W from GeoStudio software was used to run the analysis. Based on the study, the phreatic line can reduce at a slower rate inside the embankment, possibly due to the embankment material's poor permeability. Then, the FOS value remains nearly constant with less pore-water pressure dissipation. The FOS value decreases significantly after ten days of drawdown, during which the reservoir's water level is at its lowest level. However, it is observed that the FOS value recovers with time as the excess pore-water dissipates. In addition, during the drawdown process, the phreatic line is also slowly changing as time goes on.

Oya et al. [8] conducted a seepage flow-stability analysis of the riverbank of the Saigon River due to river water level fluctuation. The researcher used PLAXIS, a commercial finite element software, to run the analyses. The study shows that the FOS decreases as the water level decreases. The slope is stable when the water level is high because of hydraulic pressure from the river. However, the hydraulic pressure dissipates when the river's water level goes down, and the slope becomes unstable. Then, the phreatic line level remains higher than the river water level, which is assumed to be the cause of the instability of the slope. The instability occurs during the drawdown when the phreatic level in the ground remains at a high level due to the ground's poor permeability, causing the weight of the soil to remain high. Furthermore, the water level fluctuation can cause the removal of the hydraulic balancing forces acting on the riverbank during water drawdown, causing slope failure.

Oo et al. [9] analysed riverbank slope stability during rapid drawdown. ABAQUS and GeoStudio are used to run the analysis. The rapid drawdown occurs when the water level goes from 15 m to 30 m in 6.5 hours. Based on the results of the study, the rapid drawdown of river water level most easily leads to the occurrence of slope failure, and the

stability of the slope of the riverbank gradually increases with the dissipation of the excess pore-water pressure.

4. Methodology

The flow chart of this research's methodology is depicted in Figure 2.

4.1. Data Collection

(i) Height of slope

Based on BH1, the height of slope stated is 6.185 m, and in BH2, the height of middle slope is 3.216 m.

(ii) Slope angle

The slope angle is retrieved by using trigonometry. The site plan is used to measure the horizontal slope distance between BH1 and BH2 and BH1 and the river. Based on the measurement using a ruler and then calculating the ratio of 1 : 500, the horizontal distance from BH1 to BH2 is 5.5 m and BH1 to the river is 9 m.

(iii) Water level fluctuation

Figure 3 shows the fluctuation of the water level during slow drawdown. The data on fluctuating water level is retrieved through the borehole log report. Meanwhile, the rapid drawdown does not experience the fluctuation of water level, and it only experiences the drop of water level to 0.616 m within 6 hours.

(iv) Soil properties

Table 1 shows the summary table of soil properties according to its layer depth based on BH1 and BH2. The riverbank soil layer's hydraulic conductivity, K, is estimated to be 10-7 [10]. Then, the shear strength parameter, cohesion, angle of friction, and unit weight of soil are retrieved through estimating based on [11–13], respectively.

4.2. Procedure of Analyses. According to Figure 4, five analyses will be run to analyse the slope riverbank failure. Under seepage analysis, there will be two water transfer analyses: steady-state analysis and transient analysis. The steady-state analysis will act as the parent analysis, and the transient state analysis will run under the parent analysis for 30 days. Moreover, the transient analyses will be performed under two conditions: rapid drawdown and slow drawdown. During the seepage analyses, a seepage face will be considered along the upstream slope of the riverbank. Last but not least, a slope stability analysis will be run under both of the transient analyses.

Figure 5 shows the riverbank model created for the analyses, where region 1 shows the soil layer of the riverbank, while region 2 shows the road pavement layer of the slope.

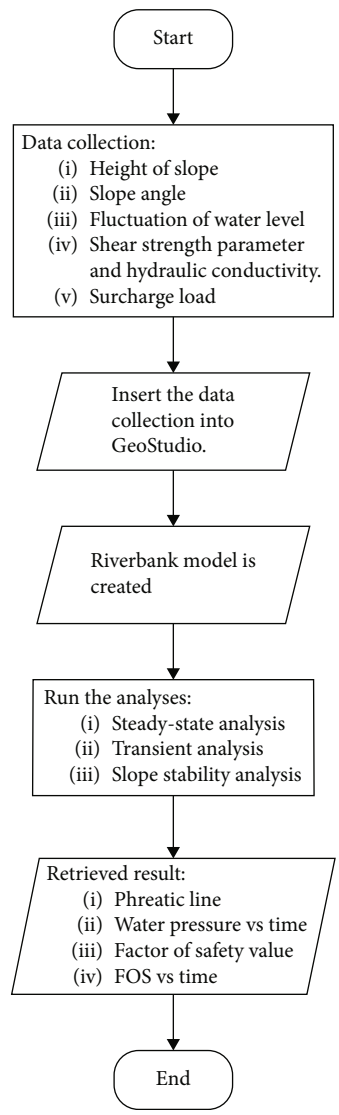


Figure 2: Flowchart of the methodology of the analyses.

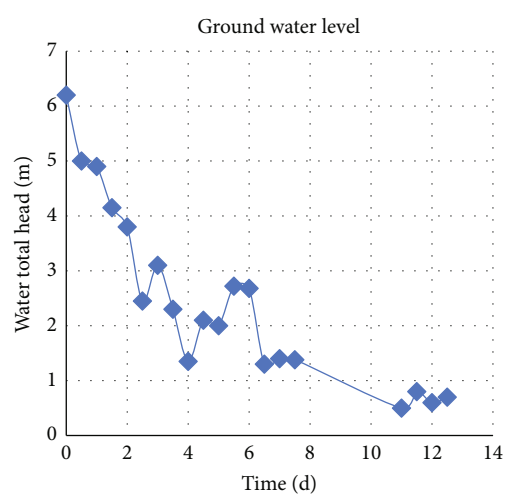


Figure 3: Water total head vs. time.

Table 1: Summary table of soil properties.

BH1						
Depth (m)	Type of soil	SPT-N	K (m/s)	C (kPa)	ø (deg)	ɣ (kN/m^3)
0-1	Side road pavement		0			
1-4.23	Silt clay	2	1.00E-07	12	14	17.30
4.23-5.50	Silt clay	2	1.00E-07	12	14	17.30
5.50-6.185	Silt clay	2	1.00E-07	12	14	17.30
BH2						
Depth (m)	Type of soil	SPT-N	K (m/s)	C (kPa)	ø (deg)	ɣ (kN/m^3)
0-1	Silt clay	2	1.00E-07	12	14	17.30
1-3.216	Silt clay	2	1.00E-07	12	14	17.30

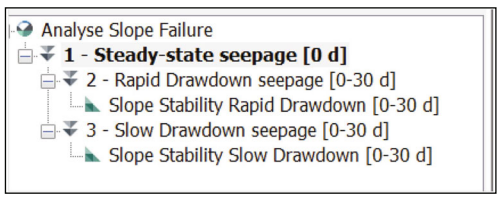


Figure 4: Five analyses to analyse slope riverbank failure.

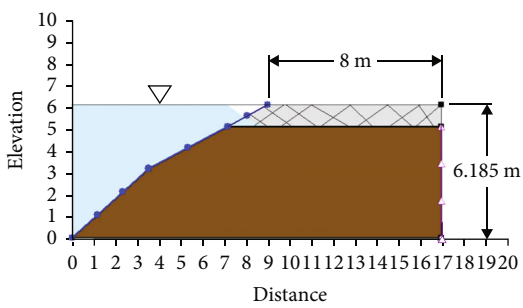


Figure 5: The riverbank model created in GeoStudio.

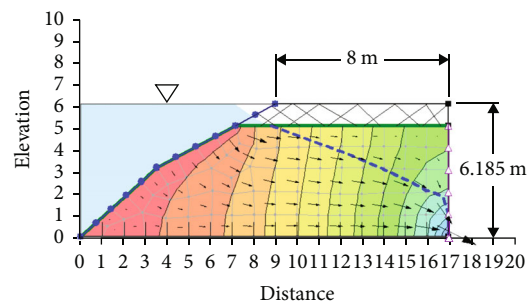


Figure 6: Steady-state analysis of riverbank.

5. Result and Discussion

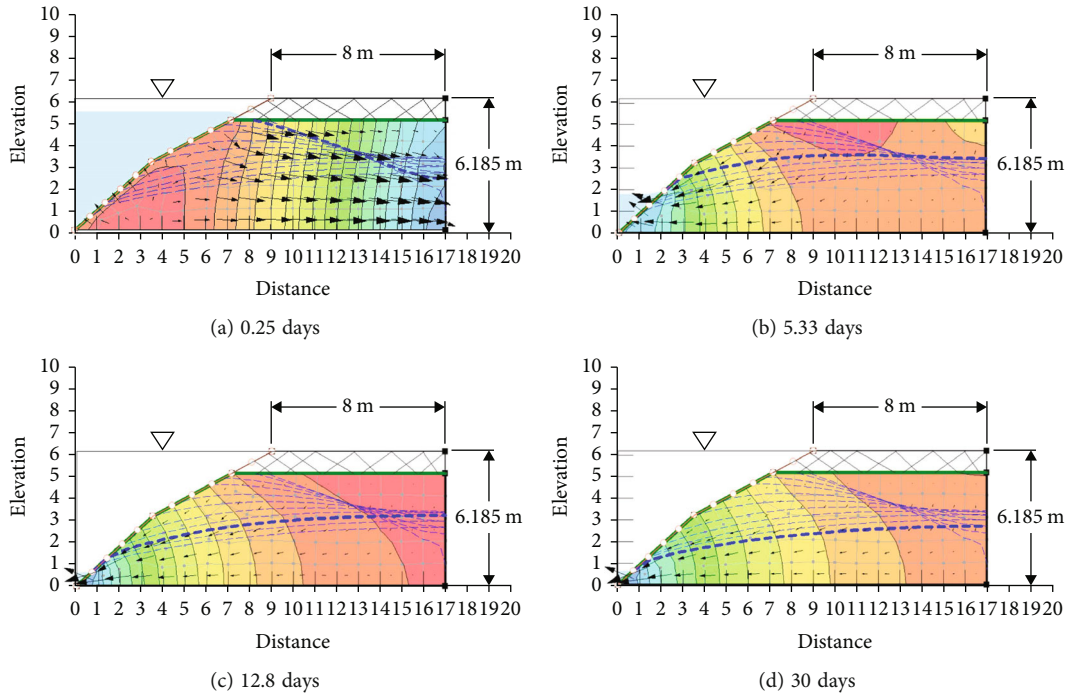
The riverbank's initial boundary condition is simulated in this study as a steady-state condition. Figure 6 shows the steady-state analysis, which simulates the riverbank under its maximum water level and will act as the parent for the rest of the analyses. Based on the figure, the phreatic line is located below the road pavement layer, showing that pore-water pressure changes below the road pavement layer.

5.1. Transient Seepage Analysis during Slow and Rapid Drawdown. Figure 7 shows the slow drawdown from Figures 7(a)–7(d), and Figure 8 shows the rapid drawdown from Figures 8(a)–8(d) experiencing the drawdown. Figures 7(a) and 7(b) show that the phreatic line is constantly changing for both drawdowns. The phreatic line location change shows the pore-water pressure change during the drawdown occurrence.

Significant differences can be seen in both drawdowns during the early stage. Figure 7(a) shows the water level is decreasing slowly, while Figure 7(b) shows the water level dropping instantaneously to 0.616 m. Figures 8(a)–8(d) show that during the early days of drawdown, the phreatic line can be located at the highest level even though the water level is way below. The phreatic line shows the upstream surface is in saturated condition due to the excess pore-water pressure in the bank having little time to dissipate and the earth's poor permeability. The saturated soil condition may increase the soil weight, decrease the soil strength, and cause slope riverbank failure. The slope stability would be influenced due to the earth's poor permeability and the soil's high weight [8].

On the other hand, Figures 7(a)–7(d) show that the water level is decreasing slowly. The phreatic line can be seen continuously changing following the slow drawdown occurrence. Not to be forgotten is the fluctuating water level in slow drawdown. The fluctuating water level may cause the up and down phreatic line movement, contributing to the variation in slope surface moisture. The variation in slope surface moisture may likely contribute to slope failure, supported by [14]. However, the change of phreatic line in slow drawdown became stable after the drawdown ended, which is after 12.625 days until 30 days.

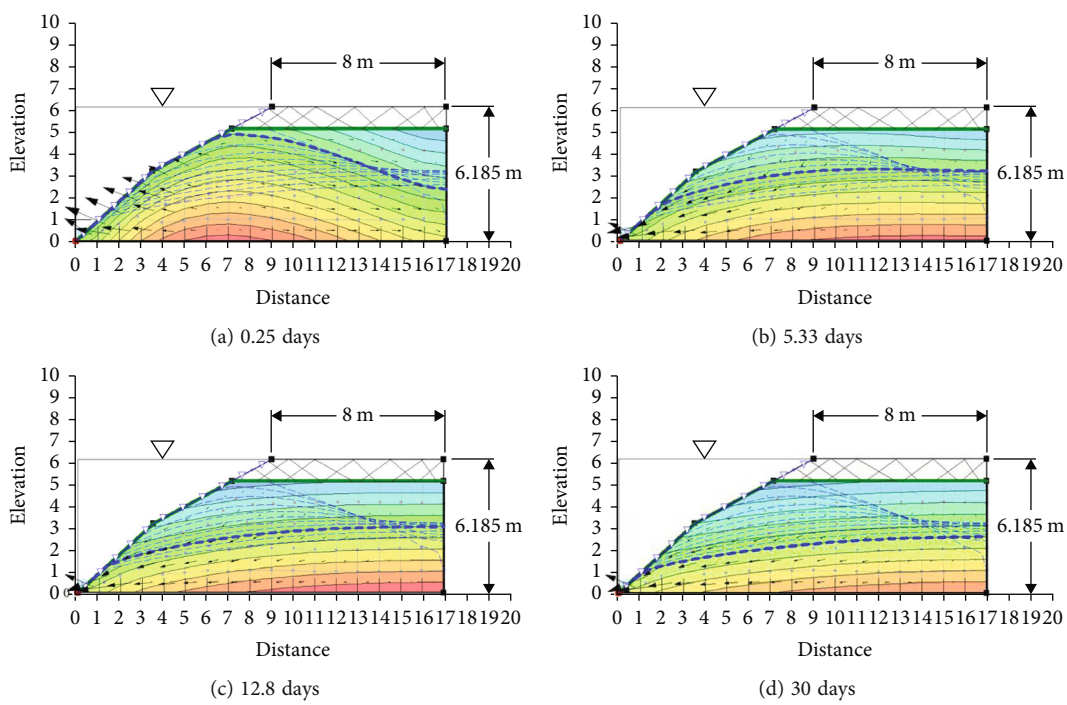
Furthermore, Figure 9 shows the water pressure vs. time graph during the slow and rapid drawdown occurrences. The water pressure taken is near the slope surface. Based on Figures 9(a) and 9(b), the water pressure decreases along with time as the drawdown occurs. The water pressure decrease means that the lateral force imparted by the water



(a) 0.25 days (b) 5.33 days

(c) 12.8 days (d) 30 days

Figure 7: (a–d) Seepage simulation of riverbank during slow drawdown.



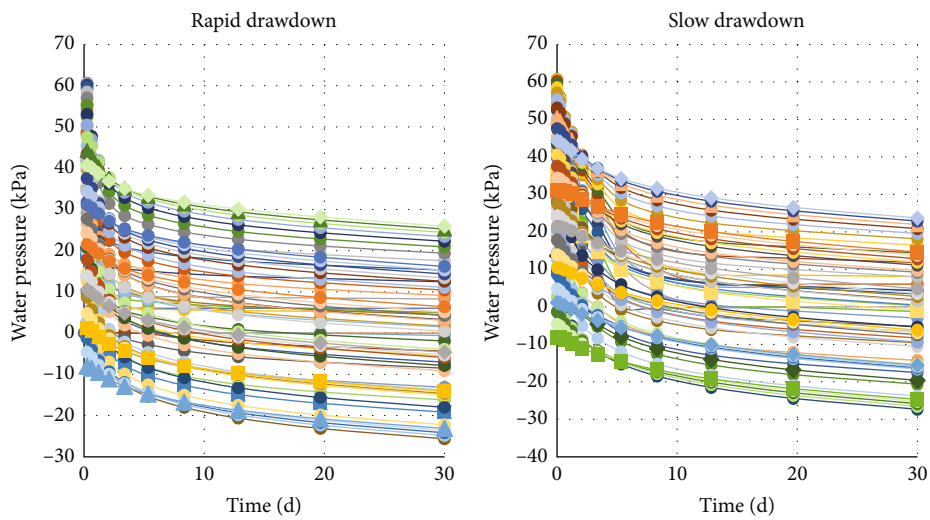
(a) 0.25 days (b) 5.33 days

(c) 12.8 days (d) 30 days

Figure 8: (a–d) Seepage simulation of riverbank during rapid drawdown.

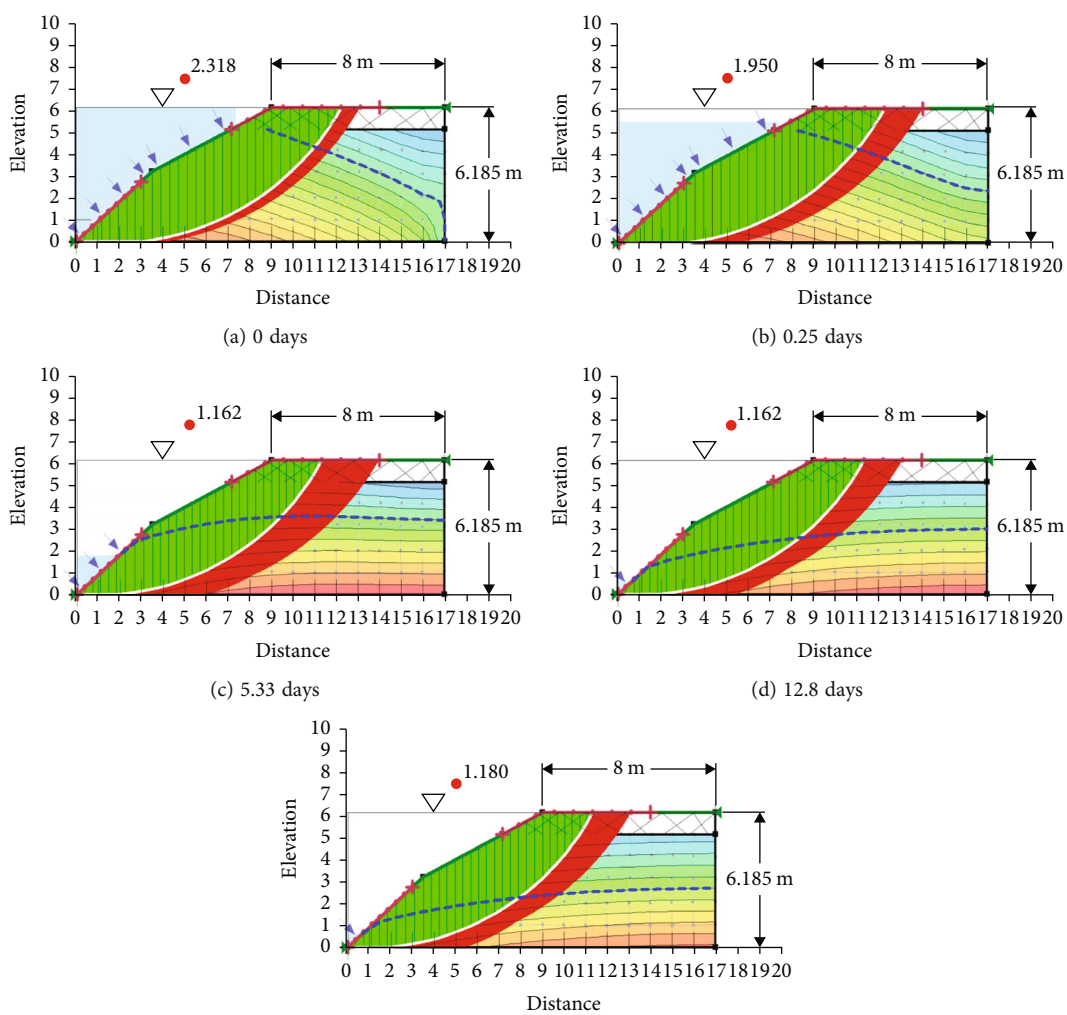
is removed. Removing lateral forces from the slope may cause an imbalance between the force exerted by the internal water pressure of the riverbank and the restricting pressure exerted by surface water on the slope. The imbalance in forces may result in slope failure [15].

5.2. Slope Stability Analysis during Slow and Rapid Drawdown. The precise riverbank drawdown slope stability analysis method is to use the transient analysis results. The slope stability analysis was run under slow and rapid drawdown seepage analysis to simulate the slope stability condition



(a) (b)

Figure 9: (a, b) Water pressure vs. time of riverbank during slow drawdown.

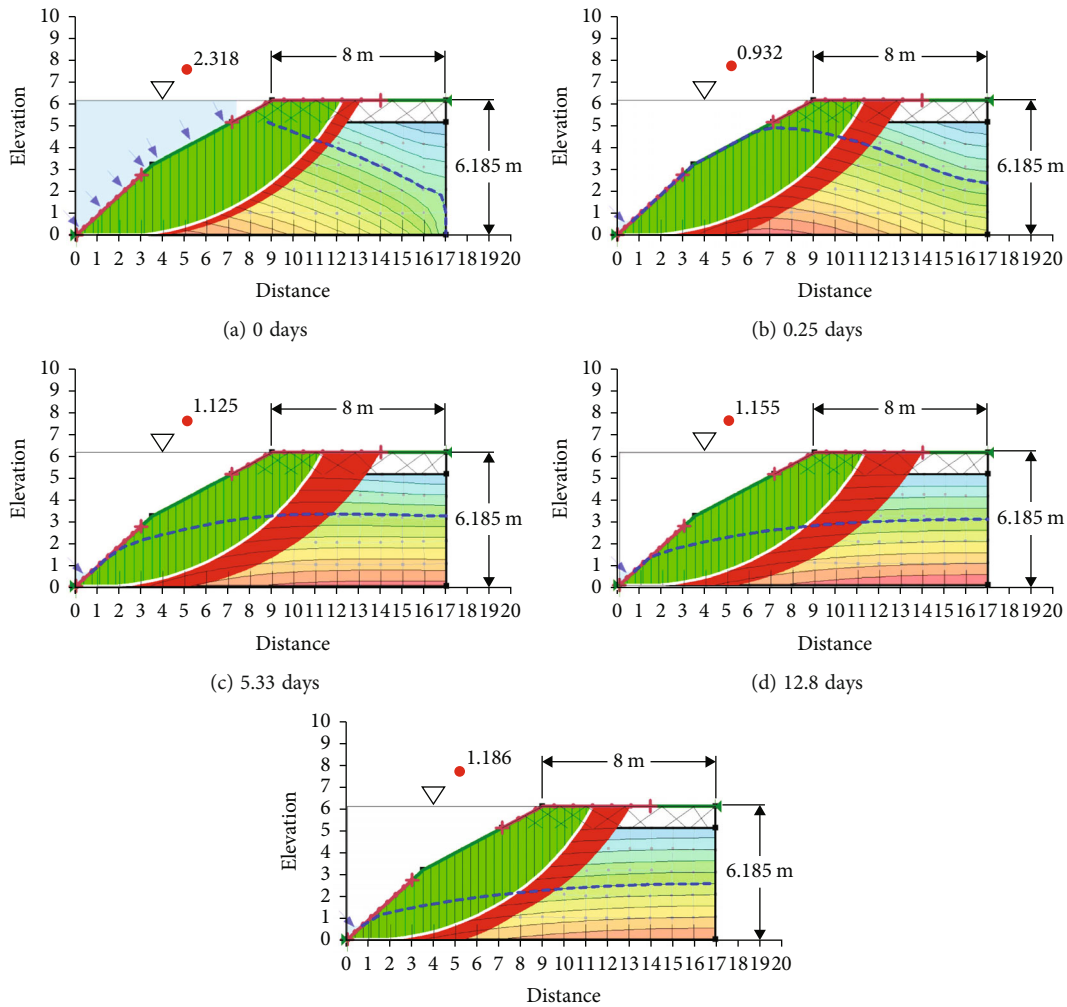


(a) 0 days (b) 0.25 days

(c) 5.33 days (d) 12.8 days

(e) 30 days

Figure 10: (a–e) Slope stability analysis simulation for slow drawdown.



(a) 0 days (b) 0.25 days (c) 5.33 days (d) 12.8 days (e) 30 days

Figure 11: (a–e) Slope stability analysis simulation for rapid drawdown.

under the drawdown event. The riverbank experiencing drawdown was simulated for 30 days to simulate the riverbank. In this type of analysis, the phreatic line decreases with time, reducing pore-water pressure over time and thus changing the amount of safety factor.

The factor of safety result was computed using the Spencer method, as shown in Figures 10(a)–10(e) and 11(a)–11(e). The minimum factor of safety for slow and rapid drawdown is 1.184 and 0.789, respectively. For slow drawdown, the minimum factor of safety occurs after the end of drawdown, which is at 12.8 days, while the minimum value of the factor of safety for rapid drawdown is at 0.25 days, right after the end of drawdown, which is at 12.8 days, while the minimum value of the factor of safety for rapid drawdown is at 0.25 days, right after the water level drops from 6.185 m to 0.616 m. The minimum factor of safety value indicates the slope stability condition most vulnerable to failure occurrence. Based on the minimum factor of safety value for both drawdowns, the rapid drawdown can be seen as the most vulnerable to slope failure. This is also shown by [9], which says that slope failure is most likely to happen when water levels drop quickly.

Figure 12 shows the graph of the factor of safety versus time for slow drawdown (Figure 12(a)) and rapid drawdown (Figure 12(b)). Figure 12(a) shows that the factor of safety value gradually decreases until it reaches its minimum factor of safety value of 2.759 to 1.184 within 12.8 days and then gradually increases over time. While Figure 12(b) shows that the factor of safety drops instantly from 2.759 to 0.789 as the water level drops to 0.616 m in 0.25 days or six hours, it also gradually increases over time. After 30 days, the safety value factor for slow and rapid drawdown is 1.234 and 1.236, respectively. The value indicates that after 30 days, the slope stability increases slowly, and the slope condition for both drawdowns is almost the same after 30 days. The value of the factor of safety after 30 days for both drawdowns also shows that the slope riverbank is vulnerable to slope failure occurrence since it is below 1.5. The graph also indicates that the slope takes a long period to achieve a stable condition.

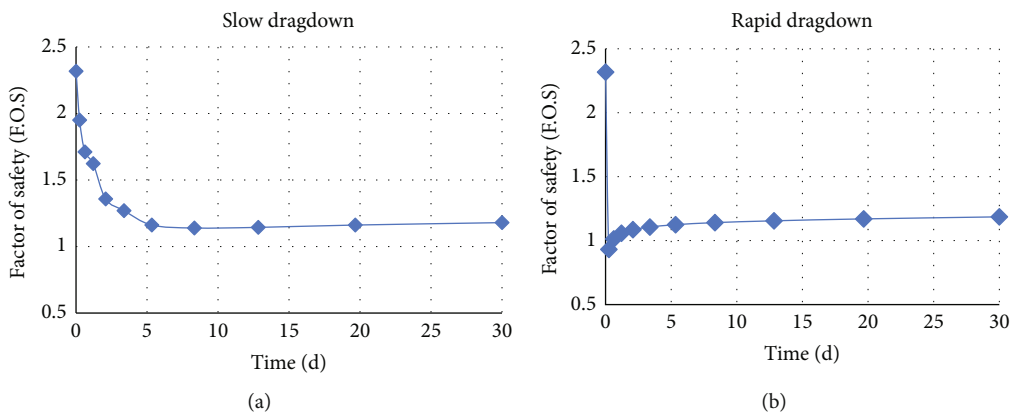


Figure 12: (a) FOS vs. time for slow drawdown. (b) FOS vs. time for rapid drawdown.

The trend of the graph in Figure 12(a) shows the factor of safety is decreasing along with the fluctuating water level from 6.185 m dropping to 0.616 m within 12.625 days, while the trend of the graph in Figure 12(b) shows that the safety factor instantaneously drops after the water level rapidly drops from 6.185 m to 0.616 m within 6 hours. The trend indicates that rapid drawdown has the highest risk of slope failure occurring during the early days of drawdown occurrence compared to slow drawdown. However, the slow drawdown is showing difficulty in predicting the time of its minimum factor of safety, which may occur due to the fluctuating water level. In conclusion, both of the drawdowns are vulnerable to slope failure occurrences.

6. Conclusion

In conclusion, the objective of this paper has been achieved. The following are the findings of the research:

The slope stability during rapid drawdown is poor during the early days of drawdown, which is based on the analysis; it shows the factor of safety drops instantaneously from 2.759 to 0.789 as the water level drops to 0.616 m within 0.25 days or six hours. The rapid drawdown recorded a low safety factor during the process because the soil weight consistently reduces, and therefore, it has affected the soil shear strength due to oversaturated conditions.

The slope stability during the slow drawdown shows that the factor of safety value decreases gradually until it reaches its minimum factor of safety value of 2.759 to 1.184 within 12.8 days, which is better than the rapid drawdown recorded; the final factor of safety is 0.784. Even though slow drawdown has a decreasing pattern for the factor of safety, once it reaches its minimum factor, which is 1.184, it gradually increases over time, so the safety value factor for slow drawdown is 1.234 after 30 days.

The rapid drawdown likely represents unrealistic conditions, as it is difficult to drain a reservoir over a short period. The slow drawdown is more likely to represent realistic conditions and, therefore, provides a more reasonable evaluation of the riverbank factor of safety during drawdown.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

Acknowledgments

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References

[1] H. Jampani and N. Bhupathi, "Stability analysis of slope with different soil types and its stabilization techniques," in *Proceeding of Indian Geotechnical Conference (GeoNEst).*, IIT Guwahati, India, December 2017.

[2] M. B. Jaksa, T. C. T. Hubble, Y. L. Kuo, C. Liang, and E. De Carli, *Riverbank Collapse Along the Lower River Murray*, The University of Adelaide, 2013, Literature Review Technical Report Series No. 13 / 15. Riverbank Collapse Along the Lower River Murray - Literature Review, (13).

[3] P. P. Dahale, T. Nalgire, A. A. Mehta, and P. D. Hiwase, "Slope stability analysis by GeoSlope," *Helix-The Scientific Explorer| Peer Reviewed Bimonthly International Journal*, vol. 10, no. 1, pp. 71–75, 2020.

[4] E. H. Vanmarcke, *Random Fields: Analysis and Synthesis*, MIT Press, Cambridge, Mass, 1983.

[5] G. Gottardi, C. G. Gragnano, I. Rocchi, and M. Bittelli, "Assessing river embankment stability under transient seepage conditions," *Procedia Engineering*, vol. 158, pp. 350–355, 2016.

[6] M. Fredlund and T. F. HaiHua Lu, *Geo-Frontiers 2011 © ASCE 2011 3419*, ASCE Geofrontiers, 2011.

[7] N. Himanshu and A. Burman, "Seepage and stability analysis of Durgawati earthen dam: a case study," *Indian Geotechnical Journal*, vol. 49, no. 1, pp. 70–89, 2019.

[8] A. Oya, H. H. Bui, N. Hiraoka, M. Fujimoto, and R. Fukagawa, "Seepage flow-stability analysis of the riverbank of Saigon River due to river water level fluctuation," *International Journal of GEOMATE*, vol. 8, no. 1, pp. 1212–1217, 2015.

[9] H. Z. Oo, L. Z. Ai, and Z. Qiu, "Numerical analysis of river bank slope stability during rapid drawdown of water level," *Study of Civil Engineering and Architecture*, vol. 2, no. 4, pp. 98–103, 2013, http://www.seipub.org/scea.

[10] J. A. Cherry and R. A. Freeze, *Groundwater (p. 370)*, Prentice-Hall, Englewood Cliffs, NJ, 1979.

[11] R. H. Karol, *Soils and Soil Engineering*, Prentice-Hall, 1960.

[12] K. Terzaghi and R. B. Peck, *Soil Mechanics in Engineering Practice*, Wiley, New York, 2nd edition, 1967.

[13] J. E. Bowles, *Foundation Analysis and Design*, McGraw Hill, 1988.

[14] Z. L. Yan, J. J. Wang, and H. J. Chai, "Influence of water level fluctuation on phreatic line in silty soil model slope," *Engineering Geology*, vol. 113, no. 1-4, pp. 90–98, 2010.

[15] B. Hossain, T. Sakai, and Z. Hossain, *River*, IOP Publishing, 2011.